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LLNL-TR-504504

B280 Final Report

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October 12, 2011

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

FMR – BUILDING 280
LIVERMORE POOL TYPE REACTOR

STRUCTURAL CONDITION ASSESSMENT
OF
REACTOR SHIELD CRACKS

DOCUMENT NUMBER:

DATES: JULY 11 – 15, 2011

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1.0 PURPOSE

Lawrence Livermore National Security, LLC (LLNS) has commissioned this independent Structural Condition Assessment as part of its Functional Management Review of the decommissioned Livermore Pool-Type Reactor (LPTR) located in Building 280 at Lawrence Livermore National laboratory (LLNL) for the purpose of addressing a potential management concern regarding the nature and impact of observed cracks in the LPTR shielding structure discovered approximately 8 months earlier. This assessment represents the final report from an initial investigation performed between July 11th and July 15th, 2011. The Exit Briefing presented by the review team at the conclusion of the on-site investigation phase is included as Attachment A.

2.0 Executive Summary

A. GENERAL

The LPTR is a tank-type, light-water moderated and cooled, low-power, test reactor constructed between 1956 and 1957 to support radiation research at LLNL (known as Lawrence Radiation Laboratory at the time). It was first taken critical on December 13, 1957 and operated almost continuously through March 31 of 1980 when operations were ceased. Decommissioning was completed later that year in November 1980. The LPTR reactor core is located within a surrounding water tank that is encased within a concrete and steel biological shielding structure. This shielding structure is housed in an 80 ft. diameter steel containment building currently designated as Building 280. It is this concrete shielding structure which encasing the water tank that is cracked and is the primary focus of this investigation.

B. REACTOR SHIELD

The reactor shield is an octagon in plan and consists of 6 feet of heavyweight (225 pcf, magnetite) concrete, surrounding the 6’-8” diameter reactor pool tank, 11’-0” from the floor slab up to the balcony level. From the balcony level the heavyweight concrete transitions, at a 60 degree angle, to 3 feet thick. At this point the concrete changes to normal weight (150 pcf) and extends up to the top of the shield wall at 25’-6”. There is a construction joint between the normal weight and the heavy weight concrete. A ¾” thick steel plate extends up 7’-0” above the floor on all exposed faces of the heavy weight concrete except at the doors on the east and west sides. The heavyweight concrete is penetrated by numerous pipes in the horizontal, vertical, and diagonal directions. The majority of aluminum pipes are located on the east side and extend from the balcony level down into the reactor.

C. OBSERVATIONS

The majority of the cracks observed are in the east wall around the penetrations near the interface of the heavy weight and normal weight concrete. However, hairline vertical cracks (1/16") were observed the full height in the 3 foot thick walls. Horizontal cracks (3/16" max.) were observed in all faces of the octagon except the west wall. Cracks on the northwest and southwest walls between the top of the steel plate and the balcony level are wider at the top than at the bottom (top of steel plate). Crack monitors had been installed approximately 6 weeks ago. There has been no indication of any movement in the width of the cracks. There is an old crack monitoring device on the vertical crack in the east wall above the balcony.

A portion of the concrete was removed at the intersection of the heavyweight and normal weight concrete, east wall, south edge. The reinforcing steel appeared to be in good condition with no corrosion and in the correct location, as shown on the design drawings. The normal weight concrete was hard and appeared to be a uniform mix of fine and coarse aggregate. Upon initial observation, the heavyweight concrete pulled apart fairly easily at the existing cracks and left behind a dusty cement surface. The magnetite aggregate appeared smooth and shinny with evidence of rust forming on some of the pieces.

D. CAUSES OF CRACKING

Searching documents for the probable cause of the cracks lead to the November 1, 1974 Safety Analysis Report (SAR). This report indicated "in the presence of moisture corrosive attack takes place on the aluminum surfaces" and "corrosion has taken place on the aluminum lines attached to the tank and buried in concrete". The corrosion on a number of drain and vent lines has been sufficient to cause leakage of reactor coolant into the (heavyweight) concrete. There existed at the time of initial reactor operation at least one faulty connection that allowed water to enter the concrete (heavyweight). This leakage was arrested to a degree when in 1970 most of the drain and vent lines were filled with epoxy and sealed.

In addition to corrosion of pipes due to moisture within the heavyweight concrete, the following items could have caused or exacerbated the cracks in the concrete:

- Earthquakes
- Heat of hydration
- Plastic Shrinkage
- Thermal cycling
- Insufficient rebar installed
- Rebar corrosion
- Concrete mix design
- Additives to the concrete mix, such as calcium chloride
- Overloading
- Irradiation

E. UNKNOWNS

The list of unknowns includes:

- Design of the structure (no calculations, no specifications, no shop drawings and no test and inspection reports for construction)
- Concrete mix design and placement of concrete
- Effects of water leakage from start of operations (heavyweight concrete deterioration at lower levels, aluminum pipe corrosion at lower elevations, rebar corrosion at lower elevations and steel shielding plate retaining moisture)
- Extent of damage from earthquake (very limited historical data available)
- Contamination levels inside reactor
- Repairs and fixes performed (no documentation)
- Soil contamination
- Condition / location of internal piping, conduit, etc.
- Stresses imparted to the reactor vessel, ports and internal pipes
- Condition of the welds for the internal components
- Possible breech of pipes internal to structure due to documented corrosion

F. STATUS OF EXISTING CONDITIONS

The status of the reactor structure is stable under its own weight. There could be a possible local failure during an earthquake. The aluminum pipes will continue to corrode. The newly discovered cracks are unchanged after two months of monitoring. Evidence of prior crack repairs was observed, therefore it is assumed the process producing the cracks may be on-going. The design did not meet code due to less than minimum reinforcement. The rebar in the lower wall may be corroding. There has been no evidence of settlement of the reactor structure. Also, there has not been a release of contamination to date as a result of the cracking.

G. RISKS

The risks associated with the reactor structure at present include:

- Breech of structure and release of contamination
- Breech of aluminum pipe and release of contamination
- Water leakage and soil contamination
- Safety of personnel which should be minimal due to restricted access
- The unknown condition of steel shielding plates

H. RECOMMENDATIONS-INVESTIGATIONS

Additional investigations are recommended and include:

- Concrete compression testing (core samples)
- Petrographic analysis of concrete
- Chemical analysis of concrete
- Mechanical and metallurgic analysis of rebar
- Extent of rebar corrosion
- Radiological survey
- Activation products

I. RECOMMENDATIONS-STRENGTHENING

Several methods were considered for strengthening the reactor structure:

- Bracing the upper concrete tower to the floor would involve construction of structural steel braces and drilling anchors into possible contaminated floor and tower concrete. New concrete foundations may have to be installed with possible interferences with underground utilities

- Installation of externally bonded FRP systems would involve removing all utilities and striping lead paint from the tower. The effectiveness of the FRP system would be reduced at the tapered transition due to all of the openings present.

- Filling the cracks with epoxy would be a short term solution and may need to be repeated due to continued cracking. Also, the quantity of epoxy is unknown.

J. RECOMMENDATIONS-MONITORING

Three methods of monitoring were considered:

- Additional crack monitors should be installed and monitored on a quarterly basis

- A base line survey should be conducted of the tower, including elevations and horizontal controls. Also, floor slab elevations should be obtained. This survey should be repeated annually.

- Radiological monitoring is on-going and should continue.

3.0 Team Composition

- John C. Ulmer, PE, SE, Supervising Structural Engineer, URS Corporation, Denver, CO
- Gary Loomis, PE, Structural Engineer, Master Engineers & Designers
- Mark Sampson, SE, Engineering & Design Division Leader, LLNL

4.0 Scope

The task of the independent structural assessment team was to examine the cracks in the concrete portions of the reactor shielding structure for the B280 decommissioned low-power nuclear test reactor. This assessment provided recommendations that include:

- Guidance about risks associated with the structure in its current condition
- Options for investigating the structure
- Conceptual options for stabilizing the structure if judged to be necessary
- Assumptions and considerations for use in developing detailed cost estimates

5.0 Reactor Shield Design and Construction (Attachment B)

The shield walls are octagonal in plan and of reinforced concrete approximately 25′-6″ in height. The thickness varies: the walls are 6′-0″ thick to a height of 11′-0″ and transitions at a 60 degree angle to 3′-0″ thick from 14′-6″ to 25′-6″. The drawings indicate a minimum compressive concrete strength of 3,000 psi at 28 days. The lower wall to 14′-6″ is heavyweight concrete (225 pcf) and the remaining 3′-0″ thick wall is normal weight concrete. The wall reinforcing is as follows:

- 6′-0″ thick wall consists of #6 at 12″ vertical and #4 at 24″ horizontal on the outside and inside faces. The outside bars are located 1′-2″ clear from the face while the interior bars are 2″ clear. There is additional #4 at 12″ bars each way near the top of the 6′-0″ thick wall. There is also a ¾″ thick steel plate extending 7′-0″ from the floor on the exterior walls.
- 3′-0″ wall consists of #4 at 12″ each way, each face with a minimum 2″ clear.

The walls surround a 6′-8″ diameter aluminum tank with a reactor at the bottom. The tank during normal operation was filled with water. There are also numerous aluminum pipes embedded in the heavyweight concrete.

The shield walls are designed to support loads due to its weight and seismic. The aluminum tank is designed for hydrostatic loads.

The reinforcing provided does not meet minimum current ACI 318 requirements, nor did it meet the minimum requirements of the ACI Code in effect at the time it was built. The minimum Code requirements for wall reinforcing is 0.0025 x gross concrete area for horizontal and 0.0018 x gross concrete area for vertical. The minimum reinforcing would then be as follows:

- 6′-0″ wall #9 rebar at 12″ each face horizontal and #8 rebar at 12″ each face vertical
- 3′-0″ wall #6 rebar at 10″ each face horizontal and #5 rebar at 12″ each face vertical

In addition, it is common to add additional vertical and horizontal bars to account for interrupted bars at openings and add diagonal reinforcing at openings and where pipes penetrate the wall face. There was no additional reinforcing shown on the design drawings.

A seismic analysis of the shield structure was performed in 1973 using the safe shutdown earthquake (SSE) for the site. The analysis utilized finite element methodology. The SSE used for the investigation is based on a postulated 5.7 magnitude earthquake. The peak horizontal acceleration is 0.5g and the vertical acceleration is 0.33g at ground level. The maximum shear stress in the concrete is 50 psi which is less than the allowable shear stress of 60 psi. The maximum tensile stress in the reinforcing steel is 65 ksi which is less than the ultimate stress of 80 ksi. The bars will yield under seismic load (40 ksi yield strength). However, this analysis did not consider the openings and penetrations at the top of the heavyweight concrete. In the transition from 6′ thick to 3′ thick walls are several large openings. The majority of these openings are on the east, southeast, and northeast faces where the most significant cracking has occurred. These openings and pipes from these openings greatly reduce the area of concrete and the amount of rebar and were not considered when checking the shear and tensile stresses at this level.

A re-analysis of selected components was performed that included:

- The foundation load. The foundation design load based on an empty vessel is 2 ksf which is less than the bearing capacity of 3 ksf provided on the drawing.
- The upper portion of the wall was evaluated for a seismic event based on an acceleration of 0.5g. The area of concern was the joint between the normal weight and heavy weight concrete. The analysis indicated no uplift due to overturning and adequate shear resistance.
- At the balcony level there is a "beam" above the door opening spanning between the southeast and northeast walls. The concern was the shear capacity during a seismic event. The shear capacity of the concrete exceeded the shear design load.

There is limited information on the construction of the walls. The design drawings show the minimum concrete strength, reinforcing steel, and approximate pour joints. The lower heavy weight concrete was to be poured in 5 lifts of approximately 2'-9" heights and the upper normal weight concrete placed in 3 lifts of approximately 3'-10" heights. There are no specifications for the concrete, mix designs, or inspection/test reports for the placement. Current codes would consider the 6'-0" thick concrete as mass concrete and there would be a concern with the buildup of the heat of hydration.

There is radioactive contamination and possible activated materials remaining inside the reactor. Hazardous materials include lead paint on the exterior of the shield walls, silica in the aggregate of the concrete and possible beryllium targets inside the reactor.

6.0 Background

Time line of documented problems:

- Startup—December 1957
- Shutdown for repairs—November 1970
- Earthquake January 1980—Greenville Earthquake
- Shutdown—March 1980
- Decommissioned—November 1980
- Earthquake Loma Prieta—December 1989
- Current Observations

7.0 November 1970 Shutdown

Information shown in the November 1, 1974 Safety Analysis Report (SAR), Section 5.2.3.3 indicates the problems with moisture in contact with magnetite concrete and aluminum surfaces. The SAR states that the reactor tank was fabricated from aluminum alloy 5052 because of its "superior corrosion resistance… …As further protection, all aluminum surfaces in contact with the [magnetite] concrete were given two coats of DuPont RA-190 Alkyd resin lacquer, each at least 25 mm thick."

The following are additional excerpts from the 1974 SAR:

"However, corrosion has taken place on the aluminum lines attached to the tank and buried in the magnetite concrete. The corrosion on a number of drain and vent lines has been sufficient to cause leakage of reactor coolant into the concrete. The lines are 6063-T6 aluminum with threaded 6061-T6 fittings except at the pool wall where the threaded fittings are B214 aluminum. The threaded joints were seal welded with an unspecified filler alloy after assembly."

"The proposed explanation for this corrosion is that there existed at the time of initial reactor operation at least one faulty connection that allowed water to enter the concrete. Approximately four years later (1961) the leak first manifested itself by a very slight seepage through the concrete in the East Thermal Column. Thereafter, corrosion started raising bumps on the insides of the instrument thimbles. These bumps resulted from the pressure of the confined corrosion products on the tube outside diameter. The leakage was arrested to a degree when in 1970 most of the drain and vent lines were filled with epoxy and sealed. At that time the leak rate dropped from 1.5 gpm to 0.06 gpm indicating that these lines were the primary source of leakage. The corrosion still taking place is more of a nuisance than a serious problem."

"A second instance of corrosion was noted in 1970. During excavation beneath the containment building floor a 6061-T6 aluminum elbow on the primary system showed corrosion on its outer surface. The line is embedded within the soil and has a bituminous coating. The coating had been damaged during the original backfilling operation and corrosion was confined to the exposed area. The elbow was replaced, recoated, and a pair of anodes attached. One anode is aluminum alloy KA-46 and the second is magnesium alloy H. No further problems have been noted."

8.0 1980 Earthquakes

On January 24, 1980, 11:00 A. M. there was an earthquake of the magnitude of 5.8, Intensity VII (Modified Mercalli scale) with two relatively large aftershocks with magnitudes of 5.2 and 4.2. A second earthquake with a magnitude of 5.8, Intensity VII struck on January 26, 1980, 6:33 P. M. Based on a post earthquake damage analysis, on the balcony level some existing cracks in the concrete appeared to have been extended somewhat and one new crack developed. Another report indicated minor cracks in the reactor shield wall was observed before the earthquake and opened slightly further after the earthquake. There is no information on location or size of cracks and no photographs.

The magnitude of these two earthquakes was equivalent to the SEE used in the 1973 evaluation (5.7 magnitude). However, the presumed free-field peak ground acceleration for the SSE event was assumed to be 0.5g in the analysis, whereas the actual peak ground acceleration for the 1980 event was found to be approximately 0.25g. Note, the LPTR experienced additional ground motion in 1989 from the 7.1 magnitude Loma Prieta earthquake, however the estimated ground motion from the event at LLNL was only approximated 0.12g.

The November 1, 1974 SAR, Figure 3.8-14, shows the maximum deformation due to thermal stress at the interface of the normal weight and heavyweight concrete. This is where the major cracking has occurred. This is also where the maximum shear stress occurs during a SSE (1974 SAR, Figure 3.8-12).

9.0 Decommissioned 1980

From the March 31, 1980 reactor shut down to November 1980 the reactor was decommissioned. The following activities were performed during the decommissioning:

- All fuel was removed
- All liquids were drained
- The top of the reactor vessel tank was sealed
- All doors and access ports were welded shut
- Access to the top of the tank and the balcony level was removed

10.0 Current Observations (Attachment C)

A visual inspection of the exterior surfaces of the concrete shield walls was performed. The following is a summary of the observations:

- There is vertical cracks full height in the 3’-0” thick walls (above the balcony level). The cracks are hairline to 1/16” wide.
- Horizontal cracks at the base of the 3’-0” thick wall on all sides except the west. The width of the crack varies to 3/16” maximum.
- There is weld splatter (during decommissioning the doors were welded shut), epoxy and caulking in the cracks. Also, there is fiberglass mesh covering some of the cracks which implies these cracks are not new and date back to when the reactor was in operation.
- The coarse aggregate in the heavyweight concrete is easily removed from the mixture.
- Crack monitors had been installed approximately 6 weeks ago. There is no indication of any movement in the width of the cracks.
- The majority of the cracks are in the east face of the tower (facing the balcony) around the penetrations near the interface of the heavyweight and normal weight concrete. Cracking appeared to be both in-plane and out of plane.
- Upon initial observation, the heavyweight concrete appeared to pull apart fairly easily at the existing cracks and left behind a dusty cement surface.
- Cracks on the northwest and southwest walls between the top of the steel plate and 11’-0” are wider at the top than at the bottom (top of steel plate).
- A small containment berm about 1” tall by 1” wide was constructed on the north and south walls at the floor slab, presumably for the purpose of retaining and collecting water leaking from the walls and/or ports. A drain line from this bermed area to an area drain has been cut into the floor slab. The steel plate is corroded along the bottom at the floor slab. Also, there is a similar bermed area installed on the east wall at the balcony level that extends in front of the northeast and southeast walls.
- There is an old crack monitoring device on the vertical crack in the east wall above the balcony.

- On the north wall there is a pour line approximately 1′-9″ below the balcony level. The 3′-0″ thick walls were poured in lifts. Cold joints were visible in this portion of the structure.
- The existing paint was removed from a portion of the east and south walls for the purpose of exposing old cracks covered by the paint, but none were observed.
- A portion of the concrete was removed at the request of the assessment team at the intersection of the heavyweight and normal concrete, east wall, south edge. The following is a summary of the observations:
    - The vertical and horizontal reinforcing in the normal weight concrete is #4 bars spaced at 12″
    - The vertical reinforcing in the heavyweight concrete are #6 bars spaced at approximately 12″. The bars were spaced around the openings in the wall. One bar extended 15″ into the normal weight concrete. The #6 bar in the heavyweight concrete is tied to the #4 vertical bar in the normal weight concrete but there was a 1 ½″ space between the bars.
    - The normal weight concrete was hard and appeared to be a uniform mix of fine and coarse aggregate.
    - Although the heavyweight concrete broke apart fairly easily at the surface of the existing cracks, the cement-aggregate conglomerate appeared significantly more sound at the interior of the structure. This discrepancy appeared to arise from the poor bonding characteristics of the magnetite aggregate to the cement matrix which allows individual pieces of aggregate to be pried off the surface.
    - Rust was observed forming on some of the magnetite aggregate pieces. The surface of the coarse magnetite aggregate was smooth and shinny.
    - There was no corrosion on the reinforcing steel or the steel box.

11.0 Research on Causes of Deterioration

There are external and internal forces which may have caused cracking in the concrete shield. The external forces are the seismic forces generated by the earthquakes in 1980 and 1989. The internal forces are generated within the concrete shielding. For concrete and reinforcing steel, the degradation mechanisms may include elevated temperature, corrosion of steel, irradiation, alkali-aggregate reaction, and dissimilar materials.

- Elevated temperature: The normal operating temperature is 200^{o} F with a possible increase in temperature during an accident (melting of the lead is 621^{o} F). Compressive strength, tensile strength, and the modulus of elasticity of concrete may be reduced by greater than 10 percent in the temperature range of 180^{o} to 200^{o} F. Also, there was heat generated caused by the hydration of concrete during construction and it is not clear what precautions were taken to limit this amount of heat. Testing of concrete samples would confirm the presence or absence of damage from temperature.

- Corrosion of steel: The pH of the concrete and the amount of chlorine ions is critical in controlling corrosion. Testing of the concrete would provide information necessary to evaluate this adequately. However, typically when there is corrosion of steel, the resulting concrete crack occurs directly over and parallel with the rebar. In the visual investigation, there was no indication of steel corroding at the balcony level. However, due to long time leakage in the heavyweight concrete there may be corrosion in the reinforcing located at the base of the wall. In addition, the base of the structure is in direct contact with the soil. This allows moisture from the soil to wick up into the lower levels of the structure causing it to remain wet most of the year, while the upper levels exposed to the air remain dry.

- Irradiation: The estimated peak neutron flux for the life of the reactor is 7.1×10^{19} neutrons/cm^2, assuming normal operation for 22 years at 3 MGW and 120 hours per week. Irradiation effects on concrete and reinforcing steel are not significant when the neutron flux is below 5×10^{19} neutrons/cm^2 and 10^{18} neutrons/cm^2, respectively. There is a reduction of strength and modulus of elasticity in concrete with a neutron flux exceeding 10^{19} neutrons/cm^2. There is an increase in yield strength and decrease in ductility in reinforcing steel with a neutron flux above 10^{18} neutrons/cm^2. Irradiation may be a consideration and testing of the concrete will confirm the presence or absence of damage. With 2" of lead shielding at the bottom around the reactor, the exposure may be considerably less and not be significant.

- Alkali-aggregate reaction: Alkali-aggregate reaction of alkali-silica reaction involves aggregate that contain silica and alkaline solutions. Alkali-silica reaction can cause expansion and severe cracking of concrete structures. Testing would identify potentially reactive constituents.

- Dissimilar materials: There is aluminum pipe embedded in the concrete and the tank is aluminum. Based on the November 1, 1974 SAR, the tank had been coated. However, the pipes have corroded and been a problem from the beginning of operations. In 1970 the pipes were filled with epoxy and sealed.

12.0 Unknowns

The research activity during this structural assessment task generated a list of unknown or undocumented items which affected the cause for the cracks observed. These unknowns are as follows:

- Design of the structure (no calculations, no specifications, no shop drawings and no test and inspection reports for construction)
- Concrete mix design and placement of concrete
- Effects of water leakage from start of operations (heavyweight concrete deterioration at lower levels, aluminum pipe corrosion at lower elevations).
- Rebar corrosion at lower elevations and steel shielding plate retaining moisture
- Extent of damage from earthquake (very limited historical data available)
- Contamination levels inside reactor

- Repairs and fixes performed (no documentation)
- Soil contamination
- Condition / location of internal piping, conduit, etc.
- Possible breech of pipes internal to structure due to documented corrosion

13.0 Findings—Status of Existing Conditions

At this time the status of the reactor concrete shield are as follows:

- The reactor structure is stable under its own weight. The shield wall was re-evaluated for the design loads—dead or weight of the concrete and seismic based on 0.5g ground acceleration. The axial stress on the concrete at the normal weight/ heavy weight concrete interface is 12 psi. This value is much less than the 3,000 psi nominal compressive strength of the concrete.
- There could be a possible local failure during an earthquake
- The aluminum pipes will continue to corrode
- The cracks are unchanged after two months of monitoring.
- Evidence of prior crack repairs was observed, therefore it is assumed the process producing the cracks may be on-going.
- The design did not meet code due to less than minimum reinforcement
- The rebar in the lower wall may be corroding
- There has been no evidence of settlement of the reactor structure
- There has not been a release of contamination to date

14.0 Findings—Risks

The risks associated with the reactor structure at present include:

- Breech of structure and release of contamination or radiation streaming
- Breech of aluminum pipe and release of contamination or radiation streaming
- Water leakage and soil contamination
- Safety of personnel which should be minimal due to restricted access
- The unknown condition of steel shielding plate

15.0 Recommendations—Investigations (Attachment D)

Additional investigations are recommended and include:

- Obtain one 4″ diameter core approximately 2.5′ in length in the 3′-0″ thick wall. Obtain one 4″ diameter core approximately 5′ in length in the 6′-0″ thick wall.
- Conduct concrete compression testing on core samples
    - To determine structural properties of the concrete
- Conduct chemical and petrographic analysis of concrete
    - To determine chemical and mineralogical constituents
    - To determine the original mix design of the concrete and water/cement ratio
    - To investigate chemical & radiological damage due to sulfates, aluminum, neutron flux, etc
    - To evaluate degree of hydration (i.e. to determine if excess heat during curing caused a loss of concrete quality)

    - To investigate the presence of microcracking
- Conduct mechanical and metallurgic analysis of rebar
    - To determine structural properties of the rebar
    - To determine type of corrosive attack on the rebar (if present)
- Determine extent of rebar corrosion
- Continue radiological surveys
- Identify activation products within the structure

16.0 Recommendations—Strengthening (Attachment E)

Several methods were considered for strengthening the reactor structure:

- Bracing the upper concrete tower to the floor would involve construction of structural steel braces and drilling anchors into possible contaminated floor and tower concrete. New concrete foundations may have to be installed with possible interferences with underground utilities

- Installation of externally bonded FRP systems would involve removing all utilities and striping lead paint from the tower. The effectiveness of the FRP system would be reduced at the tapered transition due to all of the openings present.

- Filling the cracks with epoxy would be a short term solution and may need to be repeated due to continued cracking. Also, the quantity of epoxy is unknown.

17.0 Recommendations—Monitoring

Three methods of monitoring were considered:

- Additional crack monitors should be installed and monitored on a quarterly basis

- A base line survey should be conducted of the tower, including elevations and horizontal controls. Also, floor slab elevations should be obtained. This survey should be repeated annually.

- Radiological monitoring is on-going and should continue.

18.0 Key Documents reviewed

- Safety Analysis Report for Livermore Pool Type Reactor, UCRL-51423, TID-4500, UC-41
- Design Drawings: The Austin Company reactor shield drawings and Foster Wheeler Corporation reactor arrangement drawings
- Construction photographs
- ACI 318-56 and ACI 318-08
- Seismic analysis: November 1973

19.0 Attachments

- A: Exit Briefing FMR-Building 280 Reactor July 15, 2011
- B: LPTR Reactor Shield Design and Construction
- C: Current Observations
- D: Proposal for Concrete Sampling and Testing
- E: Recommendations—Strengthening